

## FAST ARM-SWING TETHER

PATENT APPLICATION BY ANDREW W. CHOW

Fast Arm-Swing Tether (hereinafter FAST) supports the lower arms and allows a runner or walker to maintain maximum stride frequency. FAST keeps hands and arms up and virtually eliminates lower-arm rotational inertia, raising the natural frequency of pendulum motion of arm swing to ensure stride frequency is not limited by slow arms. Elevated hands also reduces the effort required to swing arms or to keep elbows locked. FAST relieves arm fatigue for long distance running or walking in addition to allowing greater arm movement. FAST could be made in any fashion as long as a frontal protrusion can provide adequate support to hang pendulum tethers to keep hands elevated.

## OBJECTIVES AND ADVANTAGES OF INVENTION

The following is claimed as objectives and advantages of the current invention: to provide hand supports, to relieve arm stress and strain, to keep hands elevated so as to increase natural frequency of pendulum arm motion, to reduce rotational inertia of lower arm, to reduce effort required to swing arms, to allow greater arm movement, and to ensure that stride frequency is not limited by slow arms.

## DESCRIPTION OF DRAWINGS

Figure 1 shows schematically a typical walker's arm in a resting position.

Figure 2 shows schematically a typical runner's arm in a resting position.

Figure 3 shows schematically a tether-supported arm in a resting position.

Figure 4 shows a FAST effective in providing the tether support in Figure 3.

## CLASSROOM PHYSICS

Texts in a first physics course typically describe the work of Newton and the motion of pendulums. Gravity and pendulum length together define the period and natural frequency of oscillation. As gravity provides for potential energy and the restoring force, a stronger gravitational pull would increase frequency. On the other hand, a longer pendulum increases inertia and thus the period. A typical classroom physics problem would require the determination of the period of a point mass with a given pendulum length and a second pendulum with the same mass spread out as a disk or a ring and with the center of gravity located at the same length. Of course, the disk or ring pendulum swings slower than the point mass due to higher rotational inertia.

## ELEMENTS OF MOTION – PHYSICS OF PENDULUM WITH EVERY STEP

When a runner, or walker, plants a foot for the next step, the pendulum model is set in motion upside down with rotation pivoting around the point contact on the ground and with the runner's body being the mass. The horizontal speed of travel defines an initial condition, and the pendulum accelerates as it falls to the ground. To keep from falling, the runner applies a force through the leg with a sufficient vertical component to counter the effect of gravity. In a sprint, the vertical component exceeds gravity so as to jettison the runner upward and to enable a long stride with both feet off the ground before the next step.

The next step is prepared by swinging the back leg forward just like a pendulum. Of course, this back swing does not necessarily behave like a passive pendulum driven only by gravity. In full stride, a runner exerts active force to pull the back leg forward and would instinctively bend at the knee to reduce rotational inertia.

Fast sprinting strides require high energy. Since gravity applies at all time and if both feet are in the air simultaneously, bobbing up and down is unavoidable. Unlike a pendulum where kinetic energy converts to gravitational potential energy for subsequent recovery, effort put into an upward bounce is largely lost upon landing for the next step. Therefore, efficient running especially for long distance requires keeping vertical movement and thus energy loss to a minimum. Good long distance runners can be observed with steady head movement and the least amount of vertical bobbing.

As efficiently as possible and to eliminate all up and down movement, one foot must always be on the ground, and the vertical component of leg force has to equal about body weight. Starting at the upside down pendulum position with leg straight down, leg force is same as body weight. As the body moves forward, the force in the leg increases to body weight divided by the cosine of the angle the leg forms with the vertical position. An immediate byproduct is the forward component measured by the sine of the leg force, and this forward force will continue to increase as the leg is pushed back farther and farther to expand the angle.

This horizontal force is necessary to overcome wind drag, but after forward resistance is overcome, this force will cause the runner to accelerate faster and faster. Obviously this can not continue forever. In reality with increasing speed, a runner will automatically switch to a sprinter mode and turn the effort into leaping through the air. An offshoot of this analysis is an obvious conclusion that keeping low and maximizing sustainable stride length and frequency will maximize performance.

Another implication of this analysis is efficiency optimization with short strides, in other words to operate in the range of small angles where the cosine is close to one and the sine is near zero. In fact, it does not require a rocket scientist to figure out the ease in walking while taking small steps, not fast but efficient. In the limiting case, it degenerates into a wheel, in essence with an infinite number of legs!

Great runners are born naturally and can do the above by instinct, in addition to having strength for long strides and stamina for high sustainable stride frequency. Runners not as equally gifted can only improve performance by training. Although personal physical output has an upper limit, it is nonetheless possible to manipulate running form by working within the framework and understanding of physics in order to maximize the frequency of strides and ultimately, running speed.

## THE OTHER PENDULUMS

An integral part of every step is the arm swing. Pulling the back leg forward for the next stride creates a rotation in one direction with respect to the foot already planted on the ground, and the simultaneous movement of the arms creates a rotation in the opposite direction. Pivoting on the ball of the foot, the counter rotations have the effect of netting out the opposing angular momentum. To maximize the frequency of strides, arm movement needs to be considered.

Figure 1 schematically illustrates a shoulder 10 with a pin joint, upper arm 20, elbow 30, lower arm 40, and hand 50. With arm fully extended and hand pointed towards the ground, arm-swing natural frequency of oscillation is slow because of the effect of a long pendulum. This fully extended position is typical of slow walking. Although a walker can force his arms to swing faster than the natural frequency of oscillation so as to increase walking pace, active force must be applied, requiring energy in the process.

Figure 2 shows a new configuration of the arm from Figure 1 with the elbow bent. In the depicted at-rest position, the elbow is pushed back due to the center of gravity of bent-arm configuration. While our bodies are constructed to allow significant arm movement forward, the elbow can be thrown back only so far. So if we exert effort to swing arms forward too much, the work done against gravity in lifting the arms up and out front would be lost on the back swing, limited by how far the elbows could be moved back. An experienced runner instinctively knows to pull the elbows back rather than push the hands forward; reaching maximum movement backwards ensures that gravitational potential energy stored in the pendulum movement is fully recovered in the forward swing that follows.

The angle formed by upper arm and lower arm determines the natural frequency of pendulum movement as it affects the center of gravity and rotational inertia. Figure 2 depicts a bent-arm position typically kept by a good runner. A tight angle provides for a high frequency of oscillation, whereas a larger angle would facilitate a lower frequency appropriate to slow running. World-class distance runners maintain arm angles less than ninety degrees.

When natural frequency of arm swing is the same as frequency of strides, minimum effort is required to keep arms moving. When frequency of strides exceeds the natural frequency of arm swing, a runner must exert effort to forcibly move the arms faster, up to the same rate as the legs. Although exerting greater leg effort is necessary to run faster, energy loss through active arm swings could be managed.

Figure 3 depicts the schematic arm from Figure 1 and 2 with a tether 60 hung from a frontal protrusion 70. The configuration in Figure 3 differs from Figure 2 as the support provided by tether 60 permits elbow relaxation with free rotational movement of the elbow joint. This innovative addition enables the lower arm to swing without rotation, essentially parallel to the ground. The lower arm has in effect become a point mass, similar to the point mass in the disk/ring classroom physics problem. Therefore, the configuration in Figure 3 has a higher natural frequency of oscillation than the model shown in Figure 2.

As a side comment, some very fast race walkers do keep their lower arms relatively parallel to the ground to increase arm-swing frequency. However, they must 1) learn to rotate their elbows at a variable rate commensurate with the arm swing, and 2) deal with an at-rest position where center of gravity still pushes the elbows back.

#### FAST ARM-SWING TETHER

The foregoing discussion highlighted principles fundamental to fast and efficient motion via tether 60 and frontal protrusion 70 as depicted in Figure 3. It should be obvious to persons knowledgeable of the art that tether means may manifest itself in many ways, for example, as a rod with rotary joints on both ends, and frontal protrusion means could be a set of football shoulder pads with a rigid rod sticking out in front. Potential designs are limited only by the imagination of capable designers. However, to complete this dissertation on FAST and to demonstrate a functional model, Figure 4 shows a frame and strap design to effectively provide a form of tether means and frontal protrusion means.

As presented in Figure 4, left tether 110 and right tether 120 support a runner's left and right hands respectively. They are made with one strap threaded through two slots in frame 130 which provides support to suspend the tethers. Thumb loops at ends of tethers could be made by looping strap ends around buckles; however, buckles are not shown to ease drawing Figure 4 by hand in india ink.

Frame bottom 140 presses against a runner's chest just below the pectorals and is hung on the two ends of bottom strap 150 which is looped around the back of a runner's neck 160. Downward force tributary to relaxed arms hanging on left tether 110 and right tether 120 keeps bottom strap 150 taut and flat on the runner's chest. Well-endowed women runners may want to attach ends of bottom strap 150 to slot holes, not shown, that are higher up away from frame bottom 140. Alternatively, frame bottom 140 could be attached to and supported by an appropriately designed sports bra.

Top strap 170 loops around the back of runner's neck as bottom strap 150, and the ends of top strap 170 attach to the top of frame 130 to provide horizontal stability. When elbows are relaxed and weigh of lower arms tugs on left tether 110 and right tether 120, frame 130 pivots off frame bottom 140 on the chest, and the top of frame 130 is pulled away from chest until top strap 170 is taut, and frame 130 is held in place.

As arm movement is defined by the tethers, runners are cautioned to only use FAST while running on surfaces that are safe and where tripping is unlikely. Runners also should practice slipping thumbs out of tether loops quickly to ensure free hand movement in the event of a fall; failing the above, runners should refrain from using FAST and run at slower and safer speeds.

#### ADDITIONAL BENEFITS

Without FAST and with bent elbows locked, a runner's upper and lower arms move together as rigid bodies, with the same angular rotation and velocity throughout when each arm is swung through the motion. Fatigue from long-distance running causes relaxation of elbows and lowering of forearms. Therefore, the daze and monotony of long distances would naturally induce a runner to slow to the natural frequency of dropping arms. On the other hand, FAST ensures the same high natural frequency is maintained at all times for optimal performance. While maximum output still depends on leg strength and overall physical capability, the lessening of arm fatigue translates nonetheless to effort saved and eventually results in an incremental increase in energy reserve that would be available for ultimate peak performance.

Figure 2 shows the at-rest position of a typical runner's arm, and Figure 3 shows the at-rest position of a FAST-supported arm. As indicated previously, effort expended in pumping an un-supported arm excessively forward is wasted as limitation of the backswing caps the maximum recapture of gravitational potential energy. On the other hand, the supported arm has a greater degree of travel before reaching the backswing limitation. Therefore, FAST-supported arms permit greater movement, enable higher arm kinetic energy, and recapture maximum energy from arm swing motion.

Although a runner can maintain a stride rate higher than the natural frequency of oscillation of the Figure 2 arm configuration, active effort must be used to force a higher rate equal to the strides. Using FAST a runner can save this additional effort through the higher natural frequency of oscillation of the FAST-supported arms. All else being the same and without doubt, FAST provides an edge on time and performance. Finally, shortening tethers can further increase natural frequency for the truly gifted runners.